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PHOTOPRODUCTION OF PROMPT PHOTONS AT NLO[a]

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A numerical program to calculate the photoproduction of prompt photons is presented. The code includes full next-to-leading order corrections to all subprocesses. The results are compared to recent ZEUS data.

1 Introduction

High energy electron–proton scattering is dominated by photoproduction processes, where the electron acts as a source of quasi-real photons which interact with the partons in the proton. These processes are of special interest since they are sensitive to both the partonic structure of the proton as well as of the photon. In particular, they offer the possibility to constrain the gluon distribution in the photon, since the subprocess $qg \to \gamma q$, where the gluon is stemming from a resolved photon, is contributing already at leading order.

The first calculations[2−4] of higher order corrections to the Compton process $\gamma q \to \gamma q$ consider only the fully inclusive cross section without the possibility to deal with *isolated* photons. More recent calculations done by Gordon/Vogelsang[5] and Krawczyk/Zembrzuski[6] take isolation into account, but only by adding a subtraction term evaluated in the collinear approximation to the fully inclusive cross section. Moreover, the code of[6] does do not contain the full set of NLO corrections.

The calculation presented here takes into account the full NLO corrections to direct as well as resolved and fragmentation parts. In addition, it includes the box contribution $g\gamma \to g\gamma$ which is formally an $\mathcal{O}(\alpha_s^2)$ correction, but known to be important[3]. A major advantage of the

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present code is also given by the fact that it is constructed as a "partonic event generator" and as such is very flexible. It produces N-tuples of partonic final state configurations which can be generated once and for all. Based on these N-tuples, suitable observables matching a particular experiment can be defined and histogrammed.

2 Theoretical formalism

The inclusive cross section for $ep \to \gamma X$ can symbolically be written as a convolution of the parton densities of the incident particles (resp. fragmentation function for an outgoing parton fragmenting into a photon) with the partonic cross section $\hat{\sigma}$

$$\begin{aligned} d\sigma^{ep\to\gamma X}(P_p, P_e, P_\gamma) &= \sum_{a,b,c} \int dx_e \int dx_p \int dz\, F_{a/e}(x_e, M) F_{b/p}(x_p, M_p) \\ & \quad d\hat{\sigma}^{ab\to cX}(x_p P_p, x_e P_e, P_\gamma/z, \mu, M, M_p, M_F)\, D_{\gamma/c}(z, M_F) \end{aligned} \quad (1)$$

where M, M_p are the initial state factorization scales, M_F the final state factorization scale and μ the renormalization scale. The subprocesses contributing to the partonic reaction $ab \to cX$ can be divided into four categories which will be denoted by 1. direct direct 2. direct fragmentation 3. resolved direct 4. resolved fragmentation. The cases 1. and 3. correspond to $c = \gamma$ and $D_{\gamma/c}(z, M_F) = \delta_{c\gamma}\delta(1-z)$ in (1), that is, the prompt[b] photon is produced directly in the hard subprocess. The cases 1. and 2. correspond to $a = \gamma$, with $F_{\gamma/e}$ approximated by the Weizsäcker-Williams formula for the spectrum of the quasi-real photons

$$f_\gamma^e(y) = \frac{\alpha_{em}}{2\pi}\left\{\frac{1+(1-y)^2}{y}\ln\frac{Q^2_{\max}(1-y)}{m_e^2 y^2} - \frac{2(1-y)}{y}\right\} . \quad (2)$$

For the resolved contributions (3. and 4.) a parton stemming from the photon instead of the photon itself participates in the hard subprocess, such that $F_{a/e}(x_e, M)$ is given by a convolution of the Weizsäcker-Williams spectrum with the parton distributions in the photon:

$$F_{a/e}(x_e, M) = \int_0^1 dy\, dx_\gamma\, f_\gamma^e(y)\, F_{a/\gamma}(x_\gamma, M)\, \delta(x_\gamma y - x_e) . \quad (3)$$

At next-to-leading order, the $\mathcal{O}(\alpha_s)$ corrections to the corresponding subprocesses are taken into account. The initial state collinear singularities are absorbed into the functions $F_{a/\gamma}(x_\gamma, M)$ resp. $F_{b/p}(x_p, M_p)$ at the factorization scales M, M_p, the final state singularities are absorbed into the fragmentation functions $D_{\gamma/c}(z, M_F)$ at the fragmentation scale M_F. As a consequence, the four subparts separately depend strongly on M, M_p, M_F and only the sum of all four parts, where the leading scale dependence cancels, has a physical meaning.

From a technical point of view, there are basically two methods to isolate the infrared singularities appearing in the calculation at NLO: The phase space slicing method and the subtraction method. The method used here is basically a phase space slicing method. For further details see [12].

In order to single out the prompt photon events from the huge background of secondary photons produced by the decays of π^0, η, ω mesons, isolation cuts have to be imposed on the photon signals in the experiment. A commonly used isolation criterion is the following: A photon is isolated if, inside a cone centered around the photon direction in the rapidity and azimuthal angle plane, the amount of deposited hadronic transverse energy E_T^{had} is smaller than some value E_T^{max} fixed by the experiment:

$$(\eta - \eta_\gamma)^2 + (\phi - \phi_\gamma)^2 \le R^2_{\exp} \; , \; E_T^{had} \le E_T^{max} \quad (4)$$

[b] By "prompt" we mean that the photon is not produced from the decay of light mesons.

Following the conventions of the ZEUS collaboration[7], we used $E_T^{max} = 0.1\, p_T^{\gamma}$ and $R_{\rm exp} = 1$. Isolation not only reduces the background from secondary photons, but also substantially reduces the fragmentation components.

3 Numerical results and comparison to ZEUS data

The numerical results can be presented only briefly here, for further details the reader is referred to [12]. For the parton distributions in the proton the MRST2 parametrization[8] is taken. The default choice for the parton distributions in the photon is AFG[9], for comparisons we also used the GRV[10] distributions transformed to the $\overline{\rm MS}$ scheme. For the fragmentation functions we use the parametrization of Bourhis et al[11]. We take $n_f = 4$ flavors and for $\alpha_s(\mu)$ we use an exact solution of the two-loop renormalization group equation, and not an expansion in $\log(\mu/\Lambda)$. The scales have been set equal to p_T^{γ}; a variation of the scales between $p_T^{\gamma}/2$ and $2p_T^{\gamma}$ leads to a variation of the cross section by less than 10%. The rapidities refer to the $e\,p$ laboratory frame, with the proton moving towards positive rapidity. To match the ZEUS conventions, we set $Q^2_{\rm max}$=1 GeV in the Weizsäcker-Williams spectrum and restrict the photon energy $y = E_\gamma/E_e$ to the range $0.2 < y < 0.9$.

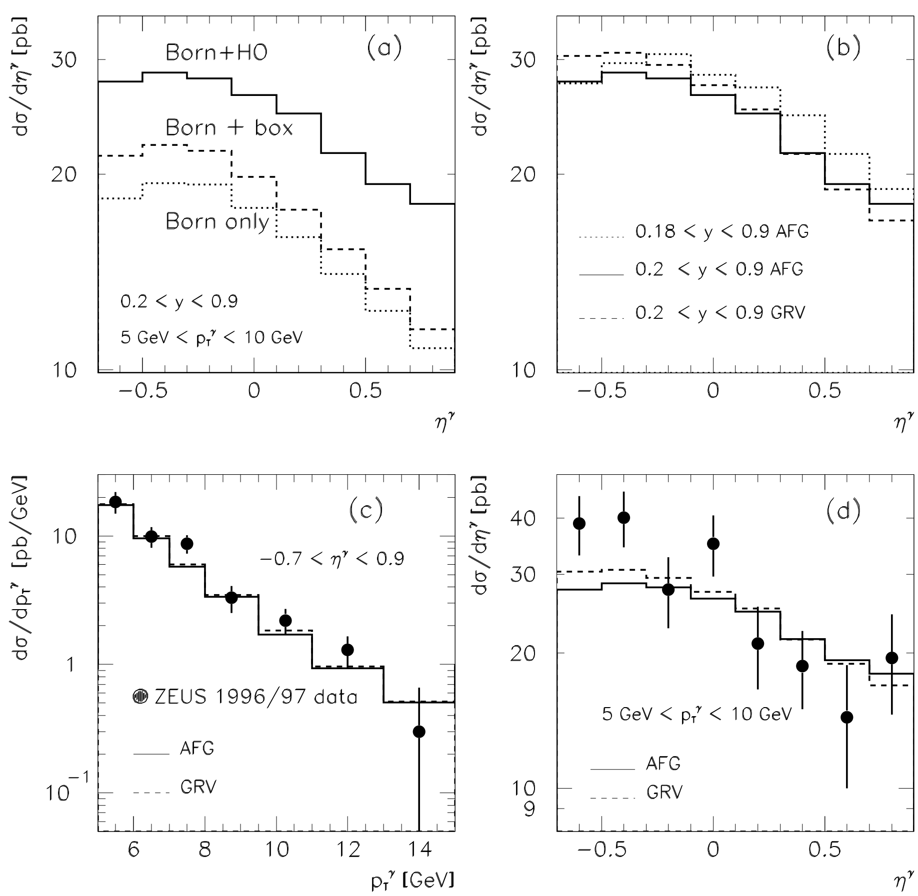

Figure 1: (a) Comparison of NLO to LO result for the photon rapidity distribution, with isolation. (b) Effect of changing the lower bound on y. Solid line: default, dotted line: lower bound on y decreased by 10%, dashed line: $0.2 < y < 0.9$ with GRV photon structure functions. (c) and (d): Comparison to 1996/97 ZEUS data.

Figure 1 (a) shows a comparison of the NLO to the leading order result and displays the magnitude of the box contribution. The higher order corrections enhance the isolated cross section by about 40%. Fig. 1 (b) illustrates the sensitivity of the cross section to a variation of the energy range of the photon: A 10% change of the lower bound on y leads to a spread which – except in the low rapidity region – is larger than the one caused by a different set (GRV) of photon structure functions. Note that experimentally, the energy of the incoming photon in photoproduction processes is reconstructed from the final hadron energies. In order to obtain the "true" photon energy y, corrections for detector effects and energy calibration have to be applied. Fig. 1 (b) shows that a good control on the error in the reconstruction of y is crucial for a detailed comparison between data and theory.

Figs. 1 (c) and (d) show a comparison to ZEUS 1996/97 data[7] for the photon p_T and rapidity distributions with two different sets of photon structure functions (AFG and GRV). For the p_T distribution the agreement is quite satisfactory; in the rapidity distribution there is a tendency that theory underpredicts the data in the backward region.

4 Conclusions

A full NLO program for the photoproduction of prompt photons has been presented. The code generates N-tuples of partonic final state configurations which serve as a starting point to define appropriate observables matching the experimental situation. The agreement between ZEUS 1996/97 data and theory is in general satisfactory; a discrepancy can be observed at low photon rapidities. With the present errors on the data, a discrimination between the AFG/GRV sets of parton distributions in the photon is not possible, but a forthcoming high statistics analysis of all 1996-2000 data announced by the ZEUS collaboration will improve this situation.

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